Software Defined Radio

For Space Signals Analysis

Intro to Software Defined Radio

What is Software Defined Radio?

- Radio communication system where traditional hardware components are implemented through software
- Replaces fixed hardware circuits with flexible software processing
- Enables reconfigurable radio systems adaptable to multiple protocols

Traditional Radio vs. SDR:

Traditional Radio	Software Defined Radio
Fixed hardware filters	Digital signal processing
Hardware mixers	Software algorithms
Analog components	ADC/DAC + CPU/FPGA
Single purpose	Multi-protocol capable

Intro to Software Defined Radio

Why SDR for Space Signals?

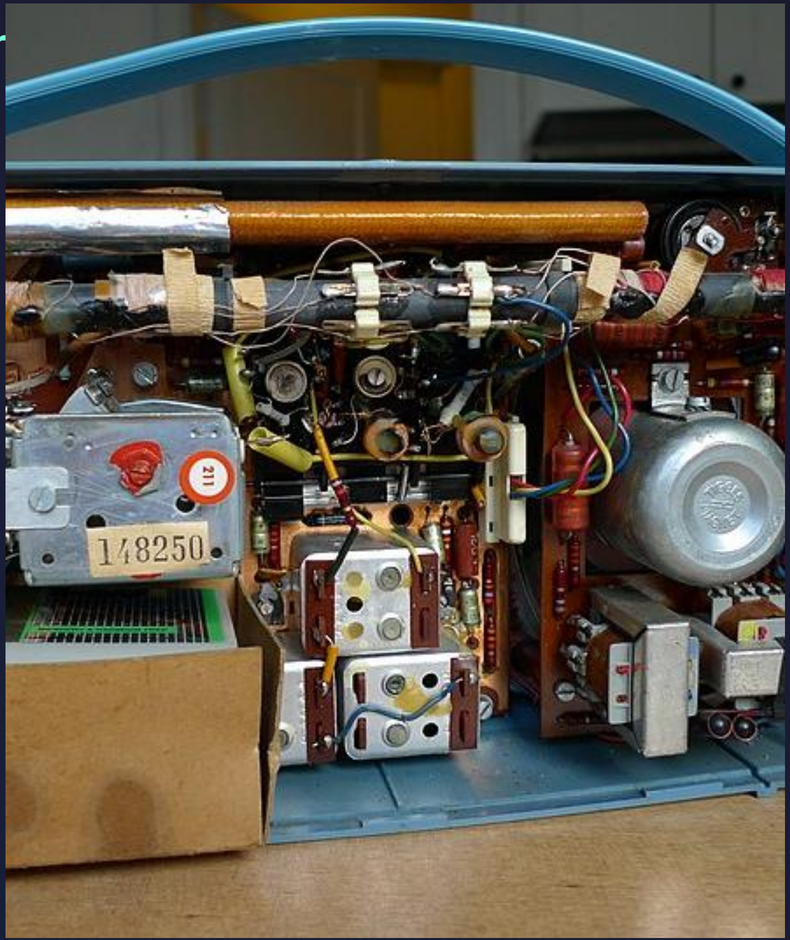
- Flexibility to decode various satellite protocols
- Cost-effective compared to dedicated hardware
- Rapid prototyping and experimentation
- Educational accessibility

Learning Objectives:

- Understand SDR fundamental concepts
- Trace the evolution of radio technology
- Identify key SDR components
- Recognize SDR applications in space communications
- Key Principle:
  - In SDR, the software is the radio changing code changes capabilities.

Traditional Radio

- Relied heavily on physical hardware components including resistors, capacitors, inductors, filters, etc. to process radio signals.
- Hardware was purpose built and configured to operate in specific frequency bands.
- Modulation/Demodulation happened in hardware and only supported what the hardware was designed for.
- Additional radios may be needed to operate in different frequencies and/or modes due to the lack of modular



OCTOBER 4, 1957

SDR VS. Traditional Radio

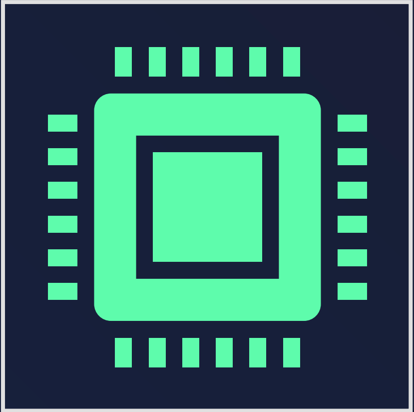
- Flexibility and Versatility
- Cost-Effectiveness
- Enhanced Capabilities
- Accessibility
- Scalability and Future-Proofing

SDR: Flexibility and Versatility

Reconfigurability: SDRs can be reprogrammed to support different frequencies, modulation types, and protocols without changing the hardware. This makes them adaptable to new standards and technologies.

Wide Frequency Range: Many SDRs can cover a broad spectrum of frequencies, from a few kHz to several GHz, allowing users to access a wide range of signals without needing multiple dedicated pieces of hardware.

SDR: Cost-Effectiveness



Reduced Hardware Needs: Because the same SDR hardware can be used for various applications through software changes, there's less need for specialized equipment. This can significantly reduce costs, especially for hobbyists, researchers, and small businesses.

Development and Deployment: The ability to test and deploy new radio functionalities through software updates rather than hardware modifications can lead to faster innovation cycles and lower development costs.

SDR: Enhanced Capabilities

Advanced Signal Processing: The use of powerful computing hardware for signal processing allows SDRs to support complex algorithms for noise reduction, signal enhancement, and encryption that would be challenging or impossible to implement in traditional radios.

Multipurpose Operation: An SDR can perform multiple functions simultaneously, such as scanning different frequencies, decoding various signal types, or even acting as both a transmitter and receiver at the same time.

SDR: Accessibility

Educational Value: SDRs provide an excellent platform for students and hobbyists to learn about radio technology, digital signal processing, and communications principles without needing expensive equipment.

Innovation and Experimentation: The open nature of many SDR platforms encourages experimentation and innovation, enabling hobbyists, academics, and professionals to explore new ideas in radio communication and signal processing.

Scalability and Future-Proofing

Longevity: As standards evolve and new communication technologies emerge, SDRs can be updated through software to remain current, reducing the need for frequent hardware upgrades.

Customization: Users can tailor SDRs to their specific needs, whether for specific research purposes, to comply with regional regulations, or to optimize performance for particular applications.

Digital Television Transition

Digital television transition

18 languages

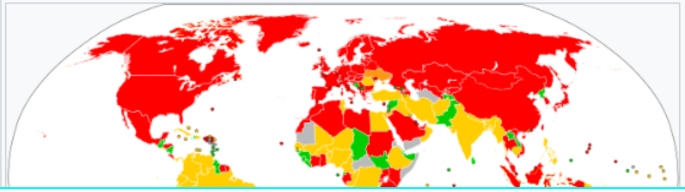
Article Talk Read Edit View history Tools

From Wikipedia, the free encyclopedia

This article needs to be **updated**. Please help update this article to reflect recent events or newly available information. *(January 2024)*

Not to be confused with Digital terrestrial television or Primary immigration.

The **digital television transition**, also called the **digital switchover** (**DSO**), the **analogue switch/sign-off** (**ASO**), the **digital migration**, or the **analogue shutdown**, is the process in which older analogue television broadcasting technology is converted to and replaced by digital television. Conducted by individual nations on different schedules, this primarily involves the conversion of analogue terrestrial television broadcasting infrastructure to digital terrestrial (DTT), a major benefit being extra freque spectrum and lower broadcasting costs, as well as impro qualities for consumers.



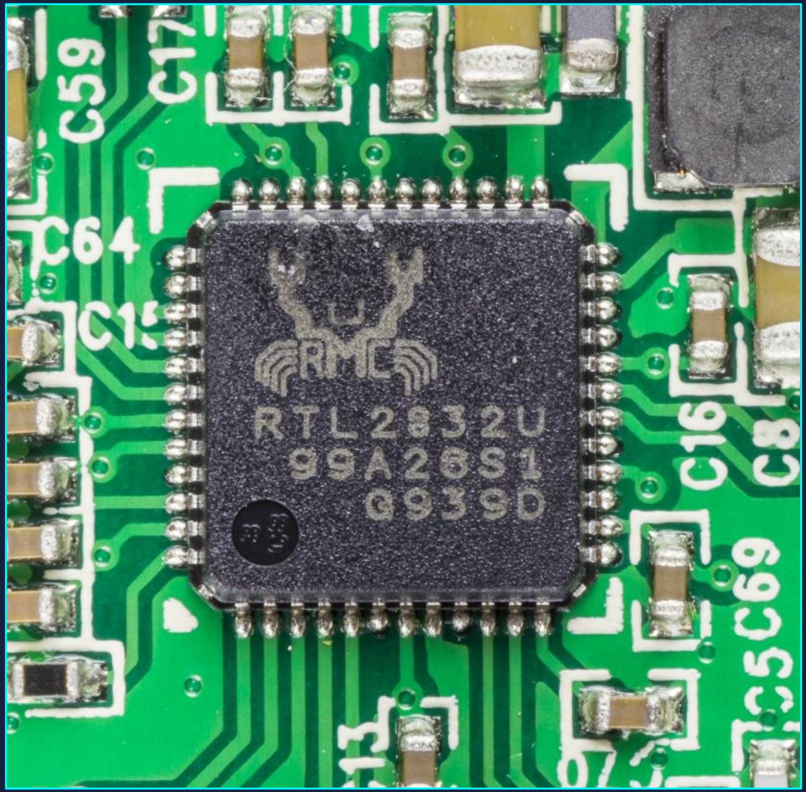
The transition may also involve analogue cable conversio Internet Protocol television, as well as analog to digital sa Transition of land based broadcasting had begun in some 2000. By contrast, transition of satellite television system underway or completed in many countries by this time. It process because the existing analogue television receivers owned by viewers cannot receive digital broadcasts; viewers must either purchase new digital TVs, or digital converter boxes which have a digital tuner and change

No Switchover planned, Both broadcasting in analog and digital and information is unavailable

June 12, 2009

SUMMARY: On June 12, 2009, the Federal Communications Commission (FCC) mandated that all U.S. based television signals must be transmitted digitally.

SDR for the Masses



SDR in Space Communications

Ground Station Applications:

- Multi-Mission Support:
  - Single hardware for multiple satellites
  - Protocol agility
  - Frequency flexibility
  - Cost efficiency
- Deep Space Communications:
  - Weak signal processing
  - Advanced error correction
  - Adaptive modulation
  - Beamforming arrays

Spacecraft Applications:

- Reconfigurable Radios:
  - In-orbit updates
  - Multi-band operation
  - Adaptive protocols
  - Cognitive radio features
- CubeSat Integration:
  - Typical CubeSat SDR:Size: 0.5U (5×10×5 cm)
  - Power: <2W receive, <5W transmit
  - Frequency: VHF/UHF/S-band
  - Processing: ARM + FPGACost: <$5000

- For SDR

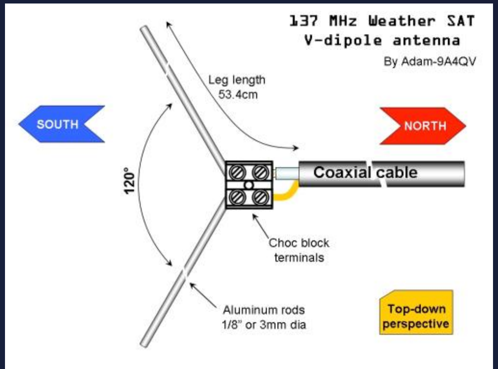
Hardware and Software for Software Defined Radio

Popular SDR Hardware Platforms

- Entry Level: RTL-SDR ($20-40)
  - DVB-T TV tuner chipset
  - Receive only
  - 24-1766 MHz coverage
  - 2.4 MSPS maximum
  - Perfect for satellite reception
- Mid-Range: HackRF One ($300)
  - Half-duplex transceiver
  - 1 MHz 6 GHz range
  - 20 MSPS bandwidth
  - Open source hardware
  - CubeSat communication capable
- Professional: USRP B200 ($700+)
  - Full duplex operation
  - 70 MHz 6 GHz
  - 56 MHz bandwidth
  - FPGA acceleration
  - Research-grade performance
- Space-Specific: ADALM-PLUTO ($150)
  - 325-3800 MHz range
  - Full duplex
  - 20 MHz bandwidth
  - Excellent for satellite work
  - Educational focus

SDR Comparison for Space Applications

Feature	RTL-SDR	HackRF	USRP	Pluto
Transmit	No	Yes	Yes	Yes
Bandwidth	2.4 MHz	20 MHz	56 MHz	20 MHz
Space Bands	Most	All	All	Most
Price	$	$$	$$$$	$$



137 MHz Weather SAT
V-dipole antenna
By Adam-9A4QV
Leg length
53.4cm
SOUTH
NORTH
120°
Coaxial cable
Choc block
terminals
Aluminum rods
1/8" or 3mm dia
Top-down
perspective

SDR Software Solutions (OSS)

- GNU Radio (The Foundation):
  - Flow graph-based signal processing
  - Extensive block library (hundreds of modules)
  - Python and C++ development
  - Hardware agnostic design
  - Industry standard framework
- SDR++ (Modern Alternative):
  - Cross-platform GUI
  - Plugin architecture
  - Real-time spectrum display
  - Satellite tracking built-in
  - Lower CPU usage
- GQRX (User-Friendly):
  - Based on GNU Radio
  - Intuitive interface
  - Recording capabilities
  - Bookmark management
  - Popular for satellite work
- SatNOGS (Space-Specific):
  - Automated satellite tracking
  - Global observation network
  - Scheduling system
  - Data aggregation
  - Open source database

Antenna Selection and Design

Choosing the Right Antenna for Space Communications

- **Antenna Types by Application:**

Antenna Type	Gain	Beamwidth	Use Case	Cost
Omnidirectional	0-3 dBi	360°	Emergency beacon	$
Yagi-Uda	7-15 dBi	30-60°	LEO tracking	$$
Helix	10-15 dBi	40-50°	Circular polarization	$$
Parabolic Dish	20-50+ dBi	<5°	GEO/Deep space	$$$$
Phased Array	Variable	Electronic	Fast tracking	

Historical Milestones in SDR Development

- 1984: SPEAKeasy Program
  - US Military's first SDR initiative
  - Goal: Single radio for all military bands
  - Proved SDR concept feasibility
  - $50M investment sparked industry
- 1991: Joseph Mitola III Coins "Software Radio“*
  - IEEE National Telesystems Conference paper
  - Defined theoretical framework
  - Vision of fully programmable radios
  - Foundation for academic research
- 1999: GNU Radio Project Begins
  - Open-source SDR framework
  - Democratized SDR development
  - Free tools for researchers
  - Community-driven innovation
- 2010: RTL-SDR Discovery
  - $20 TV dongles become SDRs
  - Mass accessibility achieved
  - Explosion in hobbyist adoption
  - Space signal reception democratized
- 2015: LimeSDR Crowdfunding
  - Full-duplex SDR under $300
  - Transmit capability for masses
  - Satellite communication possible
  - Educational revolution

Key Moments in Space SDR Applications

- 2008: First Amateur Satellite SDR Contact
  - AMSAT members use USRP for satellite QSO
  - Proved SDR viability for space communications
  - Sparked amateur radio SDR movement
  - Led to specialized satellite SDR software
- 2012: CubeSat SDR Revolution
  - Universities adopt SDR for ground stations
  - Cost reduction from $100K to <$1K
  - Enabled global CubeSat network
  - Standardized on SatNOGS platform
- 2018: Deep Space Network SDR Upgrade
  - NASA modernizes with SDR technology
  - Support for multiple missions simultaneously
  - Adaptive coding and modulation
  - Future-proof architecture
- 2020: Starlink User Terminals
  - Phased array + SDR technology
  - Auto-configuration via software
  - Proof of SDR in consumer space tech
  - Mass production viability

Real-World SDR Success Stories

Case Study 1: SatNOGS Network

- Achievement: Global satellite monitoring network
  - 500+ ground stations worldwide
  - 100% open source Automated observations
  - Crowd-sourced data

  Impact: Democratized satellite monitoring

Case Study 2: NASA SCaN Testbed

- Achievement: ISS-based SDR platform
  - Three SDR systems on ISS
  - Tested new waveforms
  - Validated cognitive radio
  - Proved space SDR viability

  Impact: Future missions use SDR baseline

Case Study 3: Amateur Radio Emergency Networks

- Achievement: Disaster communication resilience –
  - Hurricane response via SDR –
  - Multi-protocol gateway –
  - Satellite backup links –
  - Rapid deployment

  Impact: Lives saved through flexible comms

Case Study 4: University CubeSat Programs

- Achievement: Affordable space access –
  - $1000 ground stations –
  - Student-built systems –
  - Global collaboration –
  - Educational impact

  Impact: 1000+ students trained on SDR

Key Takeaways

- SDR Fundamentals
  - Software defines capability
  - Flexibility over fixed function
  - Continuous evolution possible
- Historical Context
  - 40-year journey to mainstream
  - Military → Amateur → Commercial
  - Cost reduction 1000x
- Space Applications
  - Ground stations revolutionized
  - Spacecraft gaining flexibility
  - Future is cognitive radio

Introduction to Signal Decoding and Demodulation

Core Concepts:

- What is Modulation?
  - The process of encoding information onto a radio wave
  - Like putting a letter in an envelope the radio wave is the envelope
  - The information changes some property of the wave (amplitude, frequency, or phase)
- What is Demodulation?
  - The reverse process extracting information from the radio wave
  - Like opening the envelope to read the letter
  - Converts radio signals back to useful data

Introduction to Signal Decoding and Demodulation

Core Concepts:

- What is Decoding?
  - Converting demodulated signals into meaningful information
  - Like translating the letter from code to readable text
  - Handles protocols, error correction, and data formats

- The Signal Processing Chain:

RF Signal → Demodulation → Symbol Recovery → Decoding → Data Output

↓ ↓ ↓ ↓ ↓

Modulated Carrier | Baseband Signal | Bit Stream Extraction | Protocol Parsing | Packets/ Telemetry

Introduction to Signal Decoding and Demodulation

- **Space Signal Challenges:**
  - Weak signals from distant spacecraft
  - Doppler shift from orbital motion
  - Atmospheric effects and noise
  - Multiple modulation schemes
- **Key Principle:**
  - Every space signal tells a story demodulation and decoding reveal the narrative.

Modulation Schemes in Space Communications

Amplitude Modulation Family:

- AM (Amplitude Modulation):
  - Rarely used in modern space comms
  - Simple but inefficient
  - Susceptible to noise
- OOK (On-Off Keying):
  - Used in CubeSat beacons
  - Simple implementation
  - Power efficient

Frequency Modulation Family:

- FM (Frequency Modulation):
  - Changes the frequency (pitch) of the carrier wave
  - Like a siren that goes up and down in pitch
  - Used for analog voice and weather satellite images
  - Good noise immunity static doesn't affect frequency
- FSK (Frequency Shift Keying):
  - Digital version of FM
  - Two or more discrete frequencies
  - Common in satellite telemetry
  - Robust against Doppler shift
  - Simple demodulation

Modulation Schemes in Space Communications – Cont.

Phase Modulation Family:

- BPSK (Binary Phase Shift Keying):
  - Changes the phase (timing) of the wave
  - Like flipping a wave upside down: normal = 0, flipped = 1
  - Very efficient for weak signals
  - Used in deep space missions
- QPSK (Quadrature Phase Shift Keying):
  - Uses four different phase shifts
  - Can send 2 bits at once (00, 01, 10, 11)
  - Double the data rate of BPSK
  - Common in satellite communications
- Advanced Modulations:
  - 8PSK, 16QAM, 64QAM
  - OFDM for high data rates
  - Spread spectrum (DSSS, FHSS)

Digital Demodulation Techniques

How We Extract Data from Radio Signals

- **I/Q Demodulation Fundamentals:**
  - **What is I/Q?**
    - I = In-phase component (real part)
    - Q = Quadrature component (imaginary part)
    - Together they fully describe any modulated signal
    - Like describing a location with X,Y coordinates
- **The Process:**
  - Generate a local copy of the carrier frequency
  - Create two versions: one normal (I), one shifted 90 degrees (Q)
  - Multiply the received signal by both versions
  - Filter out high-frequency components
  - Result: baseband signal ready for decoding

Digital Demodulation Techniques

- What is a PLL?
  - A circuit that locks onto and tracks a signal's frequency
  - Like a guitar tuner that automatically adjusts to match a note
  - Essential for maintaining synchronization with the satellite
- Components:
  - Phase Detector (compares input to local signal)
  - Loop Filter (smooths out variations)
  - VCO Voltage Controlled Oscillator (adjustable frequency source)
  - Feedback Path (closes the loop)
- Applications:
  - Carrier synchronization
  - Symbol timing recovery
  - Frequency tracking
  - Doppler compensation

Digital Demodulation Techniques

- **Symbol Timing Recovery:**
  - Determines exactly when to sample the signal
  - Like knowing when to take a photo of a moving object
  - Critical for accurate data extraction
  - Common algorithms: Mueller & Müller, Gardner
- **Key Considerations:**
  - Processing power requirements
  - Acquisition time vs. tracking
  - Noise performance
  - Doppler tolerance

Software Tools for Signal Analysis

Your Toolkit for Space Signal Detection

- **GQRX Real-Time Spectrum Analysis:**
  - **What is GQRX?**
    - User-friendly SDR receiver application
    - Like a very sophisticated radio scanner
    - Shows signals visually as a waterfall display
    - Built on GNU Radio but easier to use
  - **Key Features:**
    - Waterfall display shows signal strength over time and frequency
    - Multiple demodulation modes switch between AM, FM, USB, etc.
    - Recording capabilities save signals for later analysis
    - Frequency bookmarks remember satellite frequencies
  - **Typical Workflow:**
    - Tune to satellite frequency (e.g., 437.500 MHz)
    - Adjust bandwidth to match signal (usually 10-50 kHz)
    - Select appropriate demodulator (FM for voice, USB for data)
    - Fine-tune with AFC (Automatic Frequency Control)
    - Record baseband or audio for analysis

Software Tools for Signal Analysis

- **Inspectrum Offline Signal Analysis:**
  - **What is Inspectrum?**
    - Tool for analyzing recorded signal files
    - Like a microscope for radio signals
    - Helps identify modulation types and parameters
    - Essential for reverse engineering protocols
  - **Capabilities:**
    - Load and visualize I/Q recordings
    - Measure symbol rates and timing
    - Extract digital symbols from analog signals
    - Export data for further processing
- **Universal Radio Hacker (URH):**
  - **What is URH?**
    - Complete toolkit for protocol analysis
    - Like a Swiss Army knife for digital radio
    - Can demodulate, decode, and analyze
    - Includes fuzzing and attack capabilities

Signal Identification Techniques

Visual Identification Methods:

- **Waterfall Patterns:**

Pattern	Signal Type	Example
Continuous carrier	Unmodulated/CW	Beacon
Two distinct lines	FSK	Packet data
Spread spectrum	Chirp/FHSS	LoRa
Regular pulses	OOK	Telemetry

Signal Identification Techniques

Bandwidth Measurement:

- What is Bandwidth?
  - How much spectrum space a signal occupies
  - Like the width of a highway more lanes = more data
  - Measured in Hz (cycles per second)
  - Typical satellite signals: 3 kHz to 10 MHz
- How to Measure:
  - Find the signal's center frequency
  - Measure where signal drops to half power (-3dB points)
  - Distance between these points = bandwidth
  - Helps identify modulation type and data rate

Signal Identification Techniques

Modulation Classification:

- **Visual Clues:**
  - AM: Amplitude varies, frequency constant
  - FM: Frequency varies, amplitude constant
  - Phase modulation: Harder to see, need constellation diagram
  - Digital vs Analog: Digital has discrete levels, analog is continuous
- **Automated Identification:**
  - Software can analyze signal characteristics
  - Compares to database of known signals
  - Machine learning increasingly used
  - SigID Wiki community database of signal types

Doppler Shift Compensation

Dealing with Moving Satellites

- What is the Doppler Effect?
    - Frequency changes when source and receiver move relative to each other
    - Same effect as ambulance siren changing pitch as it passes
    - In space: satellites move very fast (17,000+ mph)
    - Creates significant frequency shifts we must handle
- How It Affects Satellite Signals:
    - Satellite approaching: frequency increases (sounds higher)
    - Satellite overhead: frequency is normal
    - Satellite departing: frequency decreases (sounds lower)
    - Can shift signals outside your receiver's range

Doppler Shift Compensation

Compensation Strategies:

- **Predictive Tracking:**
  - Pre-calculate Doppler curve
  - Apply frequency corrections
  - Update in real-time
- **Adaptive Tracking:**
  - AFC (Automatic Frequency Control)
  - PLL with wide capture range
  - Correlation-based tracking
- **Post-Processing:**
  - Record wide bandwidth
  - Apply corrections offline
  - Precise TLE-based correction

Weak Signal Detection Techniques

Why Are Space Signals Weak?

- Enormous distances (hundreds to thousands of miles)
- Limited satellite power (solar panels only)
- Small antennas on spacecraft
- Atmospheric losses
- Background noise from electronics and cosmos

Weak Signal Detection Techniques

Signal Processing for Sensitivity:

- **Coherent Integration:**
  - **What is it?**
    - Adding multiple copies of the same signal together
    - Signal adds up, random noise cancels out
    - Like taking multiple photos and stacking them
    - Improves signal-to-noise ratio (SNR)
  - **How it works:**
    - Collect signal over extended time
    - Align all copies properly
    - Add them together
    - Weak signal emerges from noise
- **Matched Filtering:**
  - **What is it?**
    - Using a template of expected signal
    - Like having a stencil to find a specific shape
    - Optimal way to detect known signals
    - Requires knowing signal characteristics
- **FFT-Based Detection:**
  - **What is FFT?**
    - Fast Fourier Transform converts time to frequency
    - Like a prism splitting white light into colors
    - Reveals hidden periodic signals
    - Can find signals below noise floor

Protocol Decoding Fundamentals

What is a Protocol?

- Set of rules for formatting and transmitting data
- Like the format of a postal address standardized for delivery
- Ensures sender and receiver understand each other
- Different satellites may use different protocols

Protocol Decoding Fundamentals

Common Space Protocols:

- **AX.25 Packet Radio:**
  - **What is it?**
    - Amateur radio digital protocol
    - Based on old computer networking (X.25)
    - Very common in CubeSats and amateur satellites
    - Self-contained packets with addressing
- **CCSDS Standards:**
  - **What is CCSDS?**
    - Consultative Committee for Space Data Systems
    - International standards for space agencies
    - Like USB standards but for spacecraft
    - Used by NASA, ESA, and others
- **Why use standards?**
  - **Interoperability between agencies**
  - **Proven reliable in space**
  - **Well-documented**
  - **Tools readily available**
- **Custom Protocols:**
  - **Universities often create their own**
  - **Simpler but non-standard**
  - **May lack documentation**
  - **Reverse engineering often needed**

Case Study: Decoding Weather Satellites

NOAA APT Signal Analysis

- What is APT?
  - Automatic Picture Transmission
  - Analog system from 1960s still in use
  - Transmits weather images continuously
  - Receivable with simple equipment
- Signal Characteristics:
  - Frequency: 137.1-137.9 MHz (VHF band)
  - Modulation: FM (Frequency Modulation)
  - Subcarrier: 2400 Hz AM (Amplitude Modulated)
  - Line rate: 2 lines per second
  - Image format: 2080 pixels per line
- How APT Works:
  - Satellite scans Earth line by line
  - Converts brightness to audio tone
  - AM modulates 2400 Hz carrier
  - FM modulates that onto VHF
  - Transmits continuously

Demodulation Chain:

- FM Demodulation
  - Recover audio from VHF signal
  - Results in 2400 Hz tone
- AM Envelope Detection
  - Extract amplitude variations
  - These represent pixel brightness
- Resampling
  - Convert to exactly 4160 samples/second
  - Ensures proper image geometry

Case Study: Decoding Weather Satellites

NOAA APT Signal Analysis

- Image Processing Steps:
  - Find sync pulses (marks line start)
  - Align image lines properly
  - Apply histogram equalization
  - Map to false color if desired
  - Correct for Earth curvature
- Results:
  - Real-time weather imagery
  - 4km ground resolution
  - Coverage of 3000km swath
  - Free data anyone can receive
  - Used worldwide for weather

Key Takeaways

- Demodulation Fundamentals
  - Modulation puts information on carriers
  - Demodulation extracts it back out
  - I/Q representation is foundation
  - Multiple techniques for each modulation type
- Practical Skills
  - Visual signal identification crucial
  - Master at least one tool well
  - Practice makes perfect
  - Start with known signals
- Space-Specific Challenges
  - Weak signals need integration time
  - Doppler shift must be handled
  - Protocols vary widely
  - Beacons are great for learning
- Continuous Learning
  - New satellites launch regularly
  - Protocols evolve
  - Better algorithms emerge
  - Community shares knowledge